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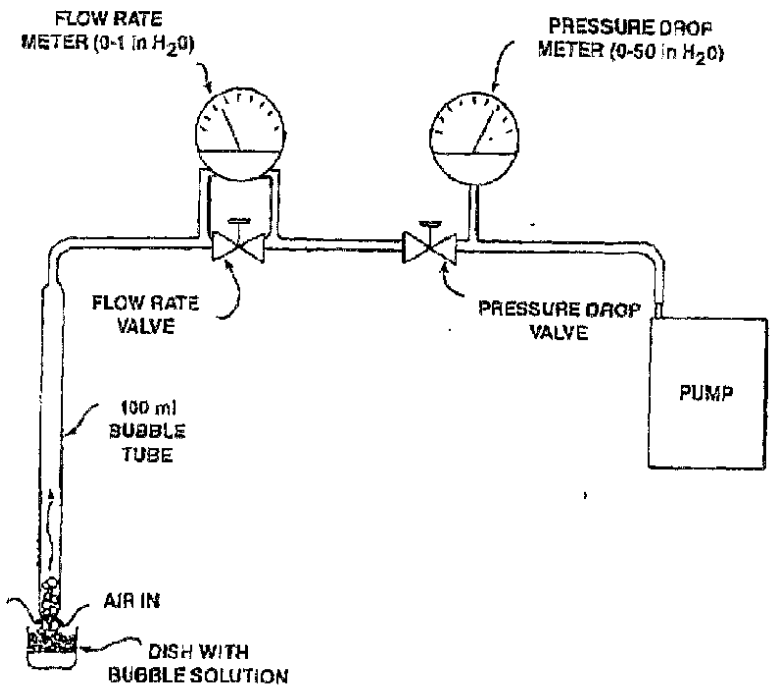

Figure 1L. Calibration Assembly for Personal Sampling Pump

Chapter IP-3

DETERMINATION OF CARBON MONOXIDE (CO) OR CARBON DIOXIDE (CO_2) IN INDOOR AIR

- Method IP-3A - Nondispersive Infrared (NDIR)
- Method IP-3B - Gas Filter Correlation (GFC)
- Method IP-3C - Electrochemical Oxidation

1. Scope

This document provides three methods for determination of CO or CO_2 in indoor air. The first method (IP-3A) employs nondispersive infrared (NDIR) spectrometry for fixed-site monitoring using a real-time continuous monitor. The second method (IP-3B) presents the use of the gas filter correlation (GFC) technique for determination of CO or CO_2 in indoor air. Method IP-3B utilizes GFC analyzers that are located at fixed sites within the monitoring area. The third method (IP-3C) utilizes electrochemical oxidation principles to determine CO in indoor air. An Appendix to Method IP-3C describes a specific portable air sampling system (PASS) using electrochemical techniques.

2. Applicability

2.1 Indoor air quality has become a significant environmental health issue because most people spend the majority of their time indoors. As with outdoor air quality and occupational exposure, monitoring pollutant concentrations indoors is essential to evaluate potential health threats and identify proper abatement approaches. Indoor CO/CO_2 emissions contribute to poor indoor air quality. With the presence of these pollutants in indoor air, there is a need to assess human exposure and at least meet ambient air and occupational standards.

2.2 Indoor CO emissions are mostly due to incomplete fuel combustion in unvented cooking and heating appliances and from consumption of tobacco products. Vehicular exhaust originating in attached or underground garages may also be a major contributor. CO is essentially nonreactive, and in the absence of indoor sources, average indoor CO concentrations are comparative to outdoor concentrations. However, when indoor sources are present, indoor levels can be much higher than those outdoors. Indoor levels can exceed the 8-hour ambient standard when indoor sources are substantial. The National Ambient Air Quality Standards (NAAQS) for CO are 9 ppm (10 mg/m^3) for an 8 hour period and 35 ppm (40 mg/m^3) for a 1 hour period.

2.3 Carbon dioxide is a colorless, odorless, and tasteless gas than can produce a debilitating effect on humans, including impaired breathing and unconsciousness. This gas is heavier than air and it seeks the lowest levels, displacing normal air. CO_2 is produced by human metabolic activity and exhaled through the lungs. The amount of CO_2 produced is a function of an individual's activity level and composition of food consumed. The average amount of CO_2 normally exhaled by an adult with an activity level equivalent to an office worker is approximately 200 mL/min.

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2.4 In addition to being a product of human respiration, CO_2 is also an indicator of inadequately vented combustion processes such as gas or oil-fired space and hot water heaters. Individuals exposed to 1.5% CO_2 for prolonged periods of time experience mild metabolic stress, while exposure to 7-10% CO_2 results in unconsciousness within a few minutes. Ventilation standards have historically been set to maintain CO_2 indoor concentrations $\leq$ 0.5%, a level which appears not to adversely affect persons with normal health. Under standards newly adopted by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) utilizing a 20 cfm/person fresh air intake rate, CO_2 indoor concentrations should be maintained below 0.08%.

DETERMINATION OF CARBON MONOXIDE (CO) OR CARBON DIOXIDE (CO_2) IN INDOOR AIR USING NONDISPERSIVE INFRARED (NDIR)

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Method IP-3A

DETERMINATION OF CARBON MONOXIDE (CO) OR CARBON DIOXIDE (CO_2) IN INDOOR AIR USING NONDISPERSIVE INFRARED (NDIR)

1. Scope

1.1 This document describes a combined method for determination of CO or CO_2 in indoor air using nondispersive infrared spectrometry. This method makes use of a commercially available nondispersive infrared (NDIR) analyzer that is located at a fixed site for continuous measurement of CO or CO_2 in indoor atmospheres.

1.2 The NDIR method described herein is based on ASTM Standard Procedure D3162-78 and 40 CFR Part 50, Appendix C. This procedure has a detection limit of approximately 0.5 ppm (0.6 mg/m^3) CO in air. NDIR analyzers are relatively insensitive to flow rate, require no wet chemicals, are sensitive over wide concentration ranges, and have short response times.

1.3 While nondispersive infrared analyzers are the most commonly used continuous, automated devices for measuring ambient level CO concentrations, other instruments have been developed and tested.

1.4 Galvanic and coulometric analyzers are two other instruments commercially available for continuously measuring CO concentrations. The function of both instruments depends on the oxidation of CO by iodine pentoxide (I_2O_5). These instruments are flow- and temperature-dependent and suffer from multiple interferences; consequently, they have not been widely used.

1.5 A mercury vapor analyzer, which depends on the liberation of mercury vapor when CO is passed over hot mercuric oxide, has been used as a portable, continuous-monitoring analyzer. Though especially adaptable for measuring low CO concentrations 0.25 ppm (0.29 mg/m^3), this instrument does not appear suitable for routine air monitoring because of numerous interferences and electronic instability.

1.6 A recently developed automated gas chromatographic system operates by quantitatively converting CO to methane (CH_4), which is subsequently semi-continuously measured by a flame ionization detector. This arrangement shows considerable promise as a monitoring device. Concentrations of from 0.1 to 1,000 ppm (0.1 to 1,150 mg/m^3) may be determined, and instrument output over this range is linear for both CO and CH_4.

1.7 The NDIR systems have several advantages over these monitoring techniques. They are:

- Insensitive to flow rates,
- Require no wet chemicals,
- Independent of room temperature change,
- Sensitive over a wide concentration range,
- Quick responding, and
- Operatable by non-technical personnel.

1.8 Consequently, this method is based upon the NDIR principle of detection of CO and CO_2 in indoor air.

2. Applicable Documents

2.1 ASTM Standards

D1356	Definition of Terms Relating to Atmospheric Sampling and Analysis
D1357	Recommended Practice for Planning the Sampling of the Atmosphere
D3195	Recommended Practice for Rotameter Calibration
D1914	Recommended Practice for Conversion Units and Factors Relating to Atmospheric Analysis
D3249	Recommended Practice for General Ambient Air Analyzer Procedures
E1	Specification for ASTM Thermometers
E180	Recommended Practice for Development of Precision Data for ASTM Methods for Analysis and Testing of Industrial Chemicals
D3162-78	Standard Test Method for Carbon Monoxide in the Atmosphere (Continuous Measurement by Nondispersive Infrared Spectrometry)

2.2 Other Documents

Laboratory and Indoor/Ambient Air Studies (1-5)
U.S. Environmental Protection Agency Technical Assistance Document (6)
U.S. Environmental Protection Agency Quality Assurance Handbook (7)

3. Summary of Detection

3.1 Nondispersive infrared analyzers have been developed to monitor not only CO or CO_2, but also SO_2, NO_x, hydrocarbons and other gases that absorb in the infrared region of the electromagnetic spectrum. The term "nondispersive" is used to describe the fact that no prisms or grating are used in the monitor to disperse the infrared energy source into component wavelengths. Rather the measurement gas itself (i.e. CO or CO_2) is used in the detector to detect wavelength, and hence species, specificity.

3.2 A broad wavelength band of infrared emission is used instead of employing monochromatic filters or diffraction gratings to isolate one particular wavelength (8). As illustrated in Figure 1A, a gas will have characteristic absorption peaks centered at specific wavelengths (λ_0) in the infrared spectrum when exposed to broad band infrared radiation (λ). The center of these absorption peaks are specific for individual compounds, as illustrated in Figure 1B.

3.3 An NDIR analyzer operates on the principle that CO (or CO_2) has a sufficiently characteristic infrared absorption spectrum such that the absorption of infrared radiation by the CO molecule can be used as a measure of CO concentration in the presence of other gases that may occur in indoor air. Although the size, shape, sensitivity, and range of these instruments vary with manufacturer, basic components and configurations are similar. Most commercially available instruments include a hot filament source of infrared radiation, a

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rotating sector (chopper), a sample cell, a reference cell, and a detector, as illustrated in Figure 2.

3.4 In operation, broad band infrared radiation is emitted from the infrared source and passes through the chopper wheel into the compartments containing the reference and sample cells. The reference cell is filled with a non-absorbing inert gas such as nitrogen or argon. The sample cell is a flow-through design enabling the passing of the gas stream of interest. Equal amounts of infrared energy enter both the sample and reference cells. If no CO or CO_2 is present in the gas stream, then the amount of radiation exiting the sample cell compartment will be equal to that exiting the reference cell. If, however, the gas stream contains molecules of CO or CO_2, then the infrared energy exiting the sample cell will be less than that exiting the reference cell because of molecular absorption.
Note: Recent models have included a distribution cell (containing 100% CO_2) and a flow-through design for the reference cell. In this design, a CO-CO_2 converter consisting of a temperature-controlled cartridge containing platinum-coated aluminum trioxide beads converts the sample gas CO to CO_2 on the reference cell side. At the same time, sample gas containing CO_2 but not converted to CO_2, flows through the sample cell. the CO-CO_2 converter causes no other change to the sample gas, thus the only difference between the sample and reference gases is the CO content. Since only the CO has been removed from the reference gas, and due to the distribution cell, all the CO_2 wavelength IR energy has been removed from both beams, then the only difference between the IR energy emanating from the sample cell and reference cell is that caused by CO wavelength absorption in the sample cell. Because all the CO_2 wavelength energy has been absorbed in the distribution cell, there can be no further absorption from the increased CO_2 concentration in the "reference" cell. All other interferents, such as water, exist similarly in both cells and do not contribute to the difference. The distinct advantage of this system over systems using cylinder reference gas or static reference cells is that all interferents, known and unknown, are similarly present in the sample and reference cells and thus their effect is cancelled.

3.5 A mathematical relationship exists between the amount of CO or CO_2 in the sample and the amount of absorption or energy attenuation. The mathematical relationship is known as the Beer-Lambert Law and is used to determine the concentration of CO or CO_2 in an air sample. The law states that the transmittance of light through a medium that absorbs light is decreased exponentially by the product acl. The Beer-Lambert Law is defined by the following equation:

$$T = I/I_o = e^{-\alpha c l}$$

where:
T = transmittance of light through sample gas
I_o = intensity of light entering the sample gas
I = intensity of light leaving the gas
c = concentration of the pollutant, mol/liter
l = distance light beam travels through sample gas, path length, cm
α = attenuation coefficient, liter/mol-cm

3.6 The attenuation coefficient, α, is dependent upon the wavelength of the radiation and also upon the properties of the molecule. The coefficient tells how much a gas species will absorb light energy at a given wavelength. If no absorption occurs, α will be zero, and the transmittance of IR energy would equal 100%. If an electronic or vibrational-rotational transition occurs in the gas at some wavelength, α will be some value, and the reduction of light energy across the path will depend upon the pollutant concentration and the original intensity, I_o, of the light beam. I_o is determined by taking a reading from the detector when no pollutant gas is in the sample cell. The concentration is obtained from the Beer-Lambert Law if α and ℓ are known. Generally, a calibration curve is generated with known gas concentrations rather than using a theoretical value for α.

3.7 The resultant IR energy exiting both the sample and reference cells now strike the detector compartment.

3.8 The uniqueness of commercially available NDIR monitors lies within the detection of the remaining IR radiation. More specifically, the detector consists of two compartments filled with equal concentrations (%) of the pollutant being monitored, i.e. CO or CO_2. Because the pollutant absorbs at discrete wavelengths, its specificity enables it to be an excellent detector for monitoring the change in IR energy entering the detector system caused by the same pollutant gas in the sample cell.

3.9 As illustrated in Figure 2, the detector compartments, containing similar concentrations of specific pollutant of interest, are separated by a thin diaphragm whose movement is detected by an induction tranceducer.

3.10 The resultant infrared signal from the reference cell strikes one compartment of the detector cell, while the resultant infrared energy from the sample cell strikes the other side of the detector cell (1). The detector functions in the following manner: when the molecules of CO or CO_2 in the detector compartments absorb infrared radiation, they absorb the energy of that radiation. This increase in energy results in the CO or CO_2 molecule becoming more active (it begins to vibrate and move more rapidly). This increase in molecular activity causes the CO or CO_2 gas to expand. However, because the gas is contained in a rigid compartment, expansion results in an increase in the pressure of the CO or CO_2 gas within the cell. The compartment receiving the reference signal receives more infrared energy and subsequently more energy is absorbed by the CO or CO_2 molecules contained within that cell. This results in a higher gaseous pressure on the reference side of the detector relative to the sample side of the detector. The thin metal diaphragm naturally bends toward the area of lower pressure (the sample side), and the amount of this deflection is measured by means of the induction transducer. This signal is then amplified and used to determine the concentration utilizing the Beer-Lambert Law. The use of CO or CO_2 in the detector compartments limits the measured absorption to one or more of the characteristic wavelengths at which CO strongly absorbs, thus providing specificity of the detector for that gas.

3.11 Because the diaphragm detector is sensitive to vibrations, the micro-flow® detector was developed. Similar to the diaphragm detector, it also contained two detector cells filled

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with CO. However, the two cells are separated by a passage way which allows gas to flow between detector reference and sample cells. The flow of gas is monitored by a mini-flowmeter. In operation, the two detector cells filled with CO absorb the unequal infrared energy. This energy is absorbed in the CO-filled detector cell, raising the gas temperature and thus its pressure. The unequal pressure rise in the detector cells, due to the unequal IR energy striking the detector cells, causes a flow from the reference detector to the sample detector cell which is measured by the micro-flow® mini-flowmeter in the connecting passage. The detector cell gas flow continues from "reference" to "sample" until the chopper blade obscures the IR energy source. At that time the transmitted energy goes to zero, the reference detector cell temperature falls to approach the temperature of the sample cell and the detector cell flow reverses to re-equalize the detector cell pressures. At the chopping rate of 10 cycles per second (8.33 for a 50 Hz installation), the micro-flow® sensor generates an alternating signal whose amplitude is proportional to CO concentration in the sample cell. The alternating micro-flow® signals are fed to an AC differential amplifier and the output fed to a synchronous rectifier phased with the chopper. The DC output of the rectifier is then filtered and amplified, then linearized and presented to the output voltage terminals as % CO.

4. Significance

4.1 CO is absorbed by the lung and reacts primarily with hemoproteins and most notably with the hemoglobin of the circulating blood (9). The absorption of CO is associated with a reduction in the oxygen-carrying capacity of blood and in the readiness with which the blood gives up its available oxygen to the tissues. The affinity of hemoglobin for CO is over 200 times that for oxygen, indicating that carboxyhemoglobin ($COHb$) is a more stable compound than oxyhemoglobin (O_2Hb). About 20% of an absorbed dose of CO is found outside of the vascular system, presumably in combination with myoglobin and heme-containing enzymes.

4.2 The magnitude of absorption of CO increases with the concentration, the duration of exposure, and the ventilatory rate. With fixed concentrations and with exposures of sufficient duration, an equilibrium is reached; the equilibrium is reasonably predictable from partial-pressure ratios of oxygen to CO.

4.3 Long-term exposures to sufficiently high CO concentrations can produce structural changes in the heart and brain. It has not been shown that ordinary ambient exposures will produce this. The lowest exposure producing any such changes has been 50 ppm (58 mg/m^3) continuously for 6 weeks. The recommended American Conference of Government Industrial Hygienists (ACGIH) permissible exposure limit for CO is 35 ppm for a 10-hour time weighted average (TWA) with a 200 ppm ceiling (10).

4.4 Consequently, due to the reliability and accuracy needed, this method recommends NDIR analyzers that have performance specifications similar to those for EPA designated reference methods (11) as outlined in Table 1 and Table 2. For monitoring ambient CO to determine compliance with the National Ambient Air Quality Standards (NAAQS), analyzers designated as reference methods are required. Portable NDIRs can be used to

screen residential environments, workplace, etc. for the presence and intensity of CO or CO_2. Use of portable NDIRs may not yield defensible quantitative information regarding CO or CO_2 concentrations. Rather, they can be used to provide a "profile" of intensity of CO or CO_2 and to assist in the placement of indoor fixed site monitors. Rigorous sampling strategy using fixed site NDIR (EPA reference models as listed in Table 2) can subsequently be instituted at specific locations based on this screening. This method will not attempt to detail the operation of portable NDIRs, which can be found in specific models users manuals.

5. Definitions

Note: Definitions used in this document and any user-prepared standard operating procedures (SOPs) should be consistent with ASTM Methods D1356, E260, and E355. All abbreviations and symbols are defined within this method at point of use. Additional definitions, abbreviations, and symbols are located in Appendices A-1 and B-2 of this Compendium.

5.1 Range - The minimum and maximum measurement limits of a monitor.

5.2 Output - Electrical signal which is proportional to the measurement; intended for connection to data recording or data processing devices. Usually expressed as millivolts or milliamps full scale.

5.3 Full scale - The maximum measuring limit for a given range of a monitor.

5.4 Minimum detectable sensitivity - The smallest amount of input concentration that can be detected as the concentration approaches zero.

5.5 Accuracy - The degree of agreement between a measured value and the true value; usually expressed as ± percent of full scale.

5.6 Lag time - The time interval from a step change in input concentration at the instrument inlet to the first corresponding change in the instrument output.

5.7 Time to 90% response - The time interval from a step change in the input concentration at the instrument inlet to a reading of 90% of the ultimate recorded concentration.

5.8 Rise time (90%) - The interval between initial response time and time to 90% of the final response after a step increase in the inlet concentration (90% response-lag time).

5.9 Fall time (90%) - The interval between initial response time and time to 90% of final response change after a step decrease in the inlet concentration to zero.

5.10 Zero drift - The change in instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation, when the input concentration is zero; usually expressed as percent full scale.

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5.11 Span drift - The change instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation, when the input concentration is a stated upscale value; usually expressed as percent.

5.12 Precision - The degree of agreement between repeated measurements of the same concentration, expressed as the standard deviation.

5.13 Operational period - The period of time over which the instrument can be expected to operated unattended within specifications.

5.14 Noise - Spontaneous deviations in measured concentrations from the mean not caused by input concentration changes.

5.15 Interference - An undesired positive or negative response caused by a substance other than the one being measured.

5.16 Interference equivalent - Quantitative interference response, measured as equivalent concentration units of the gas being measured.

5.17 Operating temperature range - The range of ambient temperatures over which the instrument will meet all performance specifications.

5.18 Operating humidity range - The range of ambient relative humidity over which the instrument will meet all performance specifications.

5.19 Linearity - The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between upper and lower calibration points.

5.20 NDIR - This measuring technique is based on absorption by a gaseous pollutant of radiation in the infrared region. This technique is termed nondispersive because no prism or grating is used to disperse the infrared radiation. Uniqueness of this approach is that compound specificity is achieved by using the pollutant being measured (CO or CO_2) in the detector compartments in a differential absorption application to discriminate the discrete wavelengths characteristic of that pollutant.

5.21 Discrimination ratio - Discrimination ratio equals the concentration of an interferent required to produce an instrument response equivalent to unit concentration of the gas being measured.

6. Interferences (8)

6.1 The degree of interference varies with individual NDIR analyzers. Manufacturer's specifications should be consulted to determine if possible interferences render the analyzer unsuitable for proposed use.

6.2 Interference may arise from gases that absorb infrared radiation in wave length bands that overlap that of carbon monoxide or carbon dioxide. Some of the possible interferents are organics, water vapor, methane, and ethane. Carbon dioxide (for CO monitors) and water vapor (for both CO and CO_2 monitors) pose the major interference problems due to their common occurrence in the atmosphere, and also due to their relatively much higher concentrations than typical CO concentrations.

Note: Concentrations of carbon dioxide found in ambient air (approximately 400 ppm) normally do not interfere with CO measurements, provided the calibration gas contains about the same concentration of CO_2. However, in air grossly contaminated with combustion products, CO_2 (in excess of 1,000 ppm) could result in positive interferences of 1 ppm or higher.

6.3 Water vapor absorbs infrared radiation to a varying degree throughout the infrared region. Its presence can be a primary positive interference in NDIR type instruments. With no correction, error from the moisture interference could be as great as 10 ppm (11 mg/m^3) CO.

6.4 Various measures may be taken to minimize moisture interference. The most obvious is a drying device in the sample inlet section of the analyzer. One device is a tube filled with silica gel or other suitable desiccant such as Drierite®. The sample air is passed over the desiccant before it enters the absorption cell. Another technique includes passing the sample air through a water saturator maintained at a constant temperature. The saturator maintains a constant humidity level in the sample gas stream. This constant humidity is also added to the calibration gases, thereby negating the moisture effects on concentration readings.

6.5 Refrigeration units in the sampling inlet systems are often used in commercial analyzers to maintain a constant, low humidity level. By cooling the sampled air, the moisture is condensed and subsequently removed from the air stream.

Note: Moisture-eliminating devices and constant humidity systems, when employed, should be used on all gases entering the analyzer - calibration, zero, and span gases as well as air samples.

6.6 Two other methods commonly employed to remove water vapor interference involve correcting the action of water vapor on the absorption phenomenon. Narrow band-pass optical filters can be used to remove those wavelengths most sensitive to water vapor from the irradiating beam. In a similar manner an "interference cell" containing water vapor and other principal interferents can be placed in line, between the infrared sources and the sample cell. The interference cell absorbs and reduces those wavelengths which overlap the CO absorption band. This reduces the interference effect of water vapor on the detector.

6.7 Another method of alleviating the interferences due to both CO_2 and water vapor (as well as other interferents) is designing the detector to contain a front and rear measuring chamber, each containing CO or CO_2, as illustrated in Figure 3. In this detector design, the infrared beams from both the reference and sample cells are geometrically combined into a single path into the detector, although the two beams are still separate due to the alternating action of the optical chopper. The front chamber is shorter than the longer rear chamber. The concentrations of pollutant gas in the two chambers are such that overall absorption, and hence the gas pressure, is equal in the two chambers (with no pollutant gas in the sample cell). Due to the peaked absorption characteristic of the detector gas,

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absorption in the front chamber is substantially greater at the center wavelengths than at the side wavelengths. In the rear chamber, however, absorption is greater at the side wavelengths because the center wavelengths have been greatly attenuated by the front chamber. This differential absorption in the two chambers helps to compensate for interference from compounds whose absorption spectra overlap that of the detector gas.

6.8 Hydrocarbons at indoor levels should not cause interferences because of the specificity of the NDIR for the component of interest's spectrum. Effects of specific hydrocarbons on the analyzer are routinely provided by the manufacturer.

7. Apparatus

7.1 Analyzer

7.1.1 Continuous CO or CO_2 monitoring system - NDIR CO or CO_2 analyzer equipped with IR source, sample and reference gas cells, sample preconditioner (if needed), detector capable of sensing differences between infrared energy levels in the sample and reference cells, adequate power supply, amplifier/ control unit, meter, and recording system. The analyzer must meet or exceed manufacturer's specifications. Table 1 contains a listing of commercially available CO analyzers. The table lists reference method analyzers from U.S. EPA's List of Designated Reference and Equivalent Methods and also includes a sampling of portable CO or CO_2 analyzers available. Those monitors designated by U.S. EPA as reference methods generally meet or exceed the suggested performance specification listed in Table 2.

7.1.2 Pump - used to flow sample air into the analytical system, if required.

7.1.3 Flow control valve - used to control sample flow rate through the analytical system.

7.1.4 Flowmeter - used to measure sample flow rate through the analyzer.

7.1.5 Moisture control system - for analytical systems that require constant humidity control, refrigeration units are available with some commercial instruments. Drying tubes (with sufficient capacity to operate for 72 hours) containing silica gel (or equivalent drying agent) may be used for short-term sampling.

7.1.6 Particulate matter filter (inline) - used to remove particulate matter from sample flow and to keep sample cell clean. Filter porosity should be 2 to 10 microns.

7.2 Calibration

7.2.1 Pressure regulator(s) - Regulators must have a nonreactive diaphragm and suitable delivery pressure. A two-stage regulator with inlet and delivery pressure gauges is recommended.

7.2.2 Flow controller - The flow controller can be any device capable of adjusting and regulating the flow from the calibration standard. If the dilution method is to be used for calibration (see Section 9.2), a second flow controller will be required for the zero-air. For dilution, the controllers must be capable of regulating the flow to ± 1%.

7.2.3 Flow meter - A calibrated flow meter capable of measuring and monitoring the calibration standard flow rate will be required. If the dilution method is used, a second flow meter will be required for the zero-air flow. For dilution, the flow meters must be capable of measuring the flow with an accuracy of ± 2%.

7.2.4 Mixing chamber - A mixing chamber is required only if the calibrator concentrations are generated by dynamic dilution of a CO standard. The chamber should be designed to provide thorough mixing of CO and zero-air.

7.2.5 Output manifold - The output manifold should be of sufficient diameter to insure an insignificant pressure drop at the analyzer connection. The system must have a vent designed to insure atmospheric pressure at the manifold and to prevent ambient air from entering the manifold.

7.2.6 Tubing - Polypropylene tubing to connect analyzer to gas cylinders when calibrating, zeroing and spanning the instrument.

7.2.7 Thermometer - used to measure monitoring area temperature.

7.2.8 Barometer - capable of measuring barometric pressure of monitoring area.

8. Reagents and Materials

8.1 Zero-air source - A source of dry zero-air that is verified to be free of contaminants that could cause detectable responses from the CO analyzer will be needed. The zero-air must contain <0.1 ppm CO; some air cylinders sold as ultrapure may actually contain 1 to 2 ppm CO. The use of a catalytic oxidizing agent such as Hopcalite on any zero-air source would be prudent.

Note: Zero air and calibration gases for CO analyzers should contain about 350 ppm CO_2 to simulate normal ambient concentrations. If synthetic air is used, CO_2 may have to be added.

8.2 Calibration standard - CO standards must be traceable (12) to a National Institute of Standards and Technology - Standard Reference Material (NIST-SRM) or a NIST/EPA approved commercially available Certified Reference Material (CRM). The CO standards must be in air unless the dilution method is used. For dilution, CO in nitrogen may be used if the zero-air dilution ratio is not less than 100:1. An acceptable protocol for demonstrating the traceability of commercial cylinder gas to an NITS-SRM or CRM cylinder gas is provided in Section 12, reference 13. In order to establish a calibration curve and determine linearity of the NDIR analyzer, the calibration gases should correspond to approximately 10, 20, 40, 60, and 80% of full scale value.

8.3 Span gas - pressurized cylinder containing CO or CO_2 concentration corresponding to 80% of full scale, best source.

9. NDIR Analyzer Operation

9.1 Installation

9.1.1 Prior to locating the fixed site NDIR sampling system, the user may want to perform "screening analyses" using a portable CO detection system, such as the PASS as outlined in Method IP-3C, Appendix, or using a portable NDIR system, examples listed in Table 2, to determine presence of CO and variances in concentration. The information gathered from the portable screening analysis would be used in developing a monitoring

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protocol, which includes the sampling system location based upon the screening analysis. After screening analysis is performed and sampling site(s) are determined, the fixed site NDIR sampling system is located.

9.1.2 Generally, CO or CO_2 fixed-site NDIR continuous monitors are designed for benchtop operation or installation into a rack. The instrument should be placed in an area that is relatively free of vibration. Appendix C-3 of this Compendium, Placement of Stationary Active Monitors, and Section 13, reference 4 gives further guidelines for monitor placement. If the analyzer is mounted on a rack, plumbing connections should be made on the rear of the cabinet for sample intake, span gas intake, zero gas intake, sample bypass and vent. Usually, on the table top analyzers, these intakes are connected to the front panel by quick-disconnect fittings. Additionally, for typical installation, primary power and recorder signal connections are also made. Portable NDIR monitors allow for much greater flexibility of employment. Some portable models are battery powered, allowing up to 8 hours of continuous operation or can be used continuously with an outside power source.

9.1.3 The manufacturer's operating instructions should include further instructions on the following: receiving inspection, typical/general installation, installation equipment required, and plumbing/electrical connections.

9.2 Operation

9.2.1 Turn-On Procedure and Initial Inspection

9.2.1.1 Turn on and inspect in accordance with specific model's user manual.

9.2.1.2 Ensure that indicators are illuminated, flow meters and pressure gauges are operational and flow meter is adjusted to obtain desired flow rate through the sample cell.

9.2.1.3 Allow the analyzer to stabilize as per user manual instructions (e.g., a minimum of two hours) prior to zeroing and spanning the instrument.

Note: Best performance can be expected if analyzer is left on continuously.

9.2.2 Manual Zero and Span Calibration

9.2.2.1 Prior to operating the analyzer, an initial calibration must be performed. The following provides procedures to measure CO or CO_2 concentrations in indoor air using the CO or CO_2 continuous monitor.

Note: Follow the manufacturer's detailed instructions when calibrating a specific analyzer.

9.2.2.2 Assemble the analyzer as illustrated in Figure 4.

9.2.2.3 Turn the power on and let the analyzer warm up. This usually requires several hours (2 hours minimum) depending on individual analyzers.

9.2.2.4 Connect zero gas to the analyzer.

9.2.2.5 Open the gas cylinder pressure valve (see Figure 4).

9.2.2.6 Adjust the secondary pressure valve until the secondary pressure gauge reads approximately (5 psi) more than the desired sample cell pressure.

Caution: Do not exceed the pressure limit of the sample cell.

9.2.2.7 Set the sample flow rate as read by the rotameter (read the widest part of the float) to the value that is to be used during sampling.

9.2.2.8 Let the zero gas flow long enough to establish a stable trace. Allow at least 5 minutes for the analyzer to stabilize.

9.2.2.9 Adjust the zero control knob until the trace corresponds to the line representing 5% of the strip chart width above the chart zero or baseline. The above is to allow for possible negative zero drift. If the strip chart already has an elevated baseline, use it as the zero setting.

9.2.2.10 Let the zero gas flow long enough to establish a stable trace. Allow at least 5 minutes for this. Mark the strip chart trace as adjusted zero and record on Multipoint Calibration Data Sheet, Figure 5.

9.2.2.11 Disconnect the zero gas.

9.2.2.12 Connect the span gas with a concentration corresponding to approximately 80% of full scale.

9.2.2.13 Open the gas cylinder pressure valve (see Figure 4). Adjust the secondary pressure valve until the secondary pressure gauge reads approximately 5 psi more than the desired sample cell pressure.

9.2.2.14 Set the sample flow rate, as read by the rotameter, to the value that is to be used during sampling.

9.2.2.15 Let the span gas flow until the analyzer stabilizes.

9.2.2.16 Adjust the span control until the deflection corresponds to the correct percentage of chart as computed by:

$$\text{Correct percentage of chart} = [C_s(\text{ppm})]/[C_f(\text{ppm})] \times 100 + 5\ \%\ \text{zero offset}$$

where:
C_s = concentration of span gas, ppm
C_f = full scale reading of analyzer, ppm

As an example where the percent zero offset is 5 and the correct percentage of chart for the span gas of 40 ppm would be:

$$40\ \text{ppm}/50\ \text{ppm} \times 100 + 5 = 85$$

9.2.2.17 Allow the span gas to flow until a stable trace is observed. Allow at least 5 minutes. Mark the strip chart trace as adjusted span and give concentration of span gas in ppm.

9.2.2.18 Disconnect the span gas.

9.2.2.19 Repeat Section 9.2.2.9 through Section 9.2.2.18 and if no readjustment is required, go to Section 9.2.3. If a readjustment greater than 1 ppm is required, repeat Section 9.2.2.9 through Section 9.2.2.10.

9.2.2.20 Lock the zero and span controls.

9.2.3 Multipoint Calibration

9.2.3.1 A multipoint calibration is required when the analyzer is first purchased, the analyzer has had maintenance which could affect its response characteristics, or when results from the auditing process show that the desired performance standards are not being met.

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9.2.3.2 A multipoint calibration required calibration gases with concentrations corresponding to approximately 10, 20, 40, 60, and 80% of full scale and a zero gas containing less than 0.5 ppm CO (see Section 8).

Note: Zero air and calibration gases for CO analyzers should contain about 350 ppm CO_2 to simulate normal ambient concentrations. If synthetic air is used, CO_2 may have to be added.

The calibration gases should be certified to be within ± 2% of the stated value and purchased in high pressure cylinders with inside surfaces of a chromium-molybdenum alloy of low iron content or other appropriate linings. The cylinders should be stored in areas not subject to extreme temperature changes nor exposed to direct sunlight. There are two acceptable methods for obtaining multipoint calibration standard concentrations. They are:

- the use of individual certified standard cylinders of CO for each concentration needed, and
- the use of one certified standard cylinder of CO, diluted as necessary with zero-air, to obtain the various calibration concentrations needed.

The equipment needed for calibration can be purchased commercially, or can be assembled by the user as illustrated in Figure 6. When a calibrator or its components are being purchased, certain factors must be considered:

- traceability of the certified calibration gases to an NIST-SRM (12) or a NIST/EPA-approved commercially available Certified Reference Manual (see Section 8),
- accuracy of the flow-measuring device or devices (rotameter, mass flow meter, bubble meter),
- maximum and minimum flows of dilution air and calibration gases, and
- ease of transporting the calibration equipment from site to site.

9.2.3.3 For an individual cylinder multipoint calibration, assemble the monitor and calibration system as illustrated in Figure 4.

9.2.3.4 Perform a manual zero and span calibration as in Section 9.2.2 and record the adjusted zero and span concentrations and their respective chart values on the Multipoint Calibration Data Sheet, Figure 5.

9.2.3.5 Connect the span gas with a concentration value corresponding to 80% of full scale, to the analyzer system.

9.2.3.6 Open the gas cylinder pressure valve until the secondary pressure gauge reads approximately 5 psi more than the desired sample cell pressure.

9.2.3.7 Set the sample flow rate as read by the rotameter (read the widest part of the float) to the value to be used when sampling.

9.2.3.8 Let the span gas flow long enough to establish a stable trace on the strip chart recorder; allow a least 5 minutes. Mark the chart trace as an unadjusted span. Record unadjusted span reading in ppm on the Multipoint Calibration Data Sheet, Figure 5.

Note: No adjustments are made at this point.

9.2.3.9 Disconnect the span gas.

9.2.3.10 Connect zero gas to the analyzer.

9.2.3.11 Open the gas cylinder pressure valve and adjust the secondary pressure valve until the secondary pressure gauge reads approximately 5 psi more than the desired sample cell pressure.

9.2.3.12 Set the sample flow rate as read by the rotameter to the value that is used when sampling.

9.2.3.13 Let the zero gas flow long enough to establish a stable zero trace on the strip chart recorder; allow at least 5 minutes. Mark the chart trace as an unadjusted zero. Record the unadjusted zero reading in ppm on the Multipoint Calibration Data Sheet, Figure 5.

9.2.3.14 Repeat Section 9.2.3.5 through Section 9.2.3.13 for each of the calibration gases with concentrations corresponding to approximately 60, 40, 20 and 10% of full scale in that order.

9.2.3.15 Fill in the information required on the Multipoint Calibration Data Sheet and construct a calibration curve of analyzer response as percent of chart versus concentration in ppm as illustrated in Figure 7. Draw a best fit, smooth curve passing through zero and minimizing the deviation of the four remaining upscale points from the curve. The calibration curve should have no inflection points, i.e., it should either be a straight line or bowed in one direction only. Curve fitting techniques may be used in constructing the calibration curve by applying appropriate constraints to force the curve through the zero. This procedure becomes quite involved; however, the most frequently used technique is to graph the curve (see Section 9.2.3.28 through Section 9.2.3.30).

9.2.3.16 Recheck any calibration point deviating more than ± 1.0 ppm CO from the smooth calibration curve. If the recheck gives the same results, have the calibration gas reanalyzed. Use the best fit curve as the calibration curve.

9.2.3.17 For a dynamic dilution multipoint calibration, assemble the analyzer and dynamic dilution system as illustrated in Figure 6.

9.2.3.18 Perform a manual zero and span calibration as in Section 9.2.2 and record the adjusted zero and span concentrations and their respective chart values on the Multipoint Calibration Data Sheet, Figure 5.

9.2.3.19 Now produce the zero air flow from the dilution system to the analyzer. The flow must exceed the total demand of the analyzer connected to the output manifold to ensure that no ambient air is pulled into the manifold vent.

Note: In lieu of connecting analyzer to manifold, one may fill Tedlar® bags with generated standards to be sampled by the NDIR.

9.2.3.20 Allow the analyzer to sample the zero air until a stable response is obtained; adjust the analyzer zero control to within ± 0.5 ppm of zero base line; and record the stable zero-air response (% scale) on the Multipoint Calibration Data Sheet.

Note: Offsetting the analyzer zero adjustment to +5% of scale is recommended to facilitate observing negative zero drift. On most analyzers this should be done by offsetting the recorder zero.

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9.2.3.21 Determine the 80% of monitor full scale. Example: For an analyzer with an operating range of 0 to 50 ppm, the 80% value would be:

$$0.80 \times 50 = 40 \text{ ppm}$$

9.2.3.22 Adjust the CO flow from the standard CO cylinder to generate a CO concentration of approximately 80% of the monitor full scale. Measure the CO flow, and record on the Multipoint Calibration Data Sheet.

9.2.3.23 Calculate the generated CO standard by the following equation:

$$(CO)_{gen} = [(CO)_{std}(Q_{co})]/[Q_{dil} + Q_{co}]$$

where:
$(CO)_{gen}$ = concentration of CO generated, by dilution, ppm
$(CO)_{std}$ = concentration of NITS-SRM or CRM CO gas standard, ppm
Q_{co} = flow rate of CO standard, L/min
Q_{dil} = flow rate of dilution air, L/min

Note: If wet test meter or bubble meter is used for flow measurement, the vapor pressure of water at the temperature of the meter must be subtracted from the barometric pressure.

Note: If both the CO and the zero-air flow rates are measured with the same type of flow meter (e.g. bubble flow meter, rotameter, mass flow meter, wet test meter, etc.), correction to standard temperature and pressure (STP) is not necessary. However, if this is not the case, then the flows of CO gas and dilution gas must be corrected to STP by the following equation:

$$Q_{co} = (Q_i)\,[(P_{bar}/760)(298/T + 273)]$$

where:
Q_{co} = flow rate of CO standard corrected to STP, L/min
Q_i = uncorrected flow rate of CO standard, L/min
P_{bar} = barometric pressure, mm Hg
T = temperature of gas being measured, °C

9.2.3.24 Allow the analyzer to sample until the response is stable; adjust the analyzer span until the required response is obtained, and record the CO recorder response on the Multipoint Calibration Data Sheet. After the zero and 80% points have been set, without further adjusting the instrument, generate four approximately evenly spaced points between zero and 80% by increasing the dilution flow (Q_{dil}) or by decreasing the CO flow (Q_{co}). For each concentration generated, calculate the CO concentrations and record the results for each point under the appropriate column on the data sheet.

Note: If substantial adjustments of the span control are necessary, recheck the zero and span adjustments by repeating Section 9.2.2.

9.2.3.25 Fill in the information required on the Multipoint Calibration Data Sheet and construct a calibration curve of analyzer response as percent of chart versus concentration in ppm, as illustrated in Figure 7. Draw a best fit, smooth curve passing through the zero and minimizing the deviation of the remaining upscale points from the curve. The calibration curve should have no inflection points, i.e., it should either be a straight line or bowed in one direction only. Curve fitting techniques may be used in constructing the calibration curve by applying appropriate constraints to force the curve through the zero. This procedure becomes quite involved; however, the most frequently used technique is to graph the curve.

9.2.3.26 Recheck any calibration point deviating more than $\pm 1.0 + 0.02\,C_c$ ppm from the smooth calibration curve. If the recheck gives the same results, have that calibration gas reanalyzed. Use the best fit curve as the calibration curve.

10. Systems Maintenance

10.1 Periodic Maintenance

Proper maintenance is necessary for successful monitor performance. Periodic maintenance should be performed to reduce equipment failure and maintain calibration integrity of the instrument as illustrated in Table 3. Instrument calibration should be checked on a schedule established after the analyzer has operated for a period of time. The sensitivity and linearity should also be checked. These instrument checks should be done at least on an annual basis. However, when any optical component (i.e., detector, cell or source) is changed, the linearity and selectivity of the instrument should be confirmed. The settings of the zero and span controls of instruments which operate continuously should be checked as often as required. A log of these settings and a service and repair log should be kept to assist in evaluating maintenance difficulties. Figure 8 illustrates a monthly maintenance check sheet for a typical NDIR analyzer.

10.2 Routine Maintenance

Regular checks of the instrument and its operation are mandatory. Even though a system may provide excellent quality data initially, without routine maintenance and system checks the quality of the data will degenerate with time. Table 3 provides a routine servicing schedule for a typical NDIR analyzer. Follow all routine maintenance procedures specified in the manufacturer's instruction manual.

10.2.1 Sampling system - The sampling system to which the analyzer is connected must be checked at regular intervals according to a maintenance schedule based on the components used in the specific application. Sampling system maintenance normally includes the following steps:

- checking the entire system for leaks and proper flow rates,
- cleaning and/or renewing sample system components,
- ensuring that calibration cylinders are shut off when not in use,
- ordering filled and assayed cylinders at intervals which include ample lead time to ensure continuous supply of calibration gas,
- checking operation of pumps, recorders, motors, timers and other commercial components by referring to manufacturer's instructions,
- checking and/or cleaning the entire sampling system, including the sample cell in the analyzer, when abnormal sample conditions occur, such as when slugs of water, dirt or oil are introduced, or high temperature or pressure conditions arise.

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10.2.2 Daily servicing - Automatic 80% full scale span (40 ppm) and zero precision checks should be performed utilizing the instrument's automatic zero/span standardization feature (if so equipped) and individual secondary standard gases of CO in air with the above concentrations.

10.2.3 Each visit servicing - Verify that the zero and span potentiometer settings are at the proper position. Likewise, verify that the sample cell flow is reading correctly and at the proper setting. Plot the daily zero, precision check, and span values on their respective days on the Maintenance Check Sheet. If any of the zero and span values exceed 5% of stated value, perform a manual zero and span check and adjust the analyzer to the correct zero and span values using the front panel zero and span potentiometer, respectively. If there is insufficient range in the span potentiometer, a multipoint calibration must be performed. Record the adjusted ppm values and zero and span potentiometer settings on the monthly Maintenance Check Sheet (see Figure 8).

10.2.4 Weekly servicing - At least once per week replace the Teflon® sample inlet particulate filter. Note the filter cleanliness and vary the replacement frequency accordingly. Change the filter even if only a slight particulate coating or discoloration is visible. Perform a leak check weekly and whenever the loosening or tightening of a fitting is involved in maintenance procedures. Using an individual cylinder, introduce a 20% of full scale (10 ppm) intermediate span gas at ambient pressure upstream of the sample pump as a precision check. Maintain the same excess flow each time the manual precision check is performed. The manual precision check should be within 10% of value. If not, investigate the cause and initiate repairs.

10.2.5 Monthly servicing - Inspect the water trap filter for particulate loading and replace if necessary. Note the filter cleanliness and adjust the replacement frequency accordingly. Check the span gas solenoid valve for leakage. Replace valve if necessary. Record the results and the date of the check on the Monthly Maintenance Check Sheet. An analyzer multipoint calibration should be performed monthly.

10.2.6 Quarterly servicing - Inspect and clean the filters downstream of the sample and reference flow meters. Note the filter cleanliness and adjust the cleaning frequency accordingly.

10.2.7 Semi-annual servicing - Perform an electronic bias adjustment utilizing the procedures outlined in the manufacturer's instruction manual. Perform a source balance adjustment utilizing the procedures outlined in the manufacturer's instruction manual.

10.2.8 Cell walls and windows - Inspect cell walls and windows for cleanliness and clean if necessary utilizing the procedures outlined in the manufacturer's instruction manual. Do not clean with cloth or paper towel; cleaning should be performed using distilled water followed by isopropyl alcohol and air drying.

10.3 Preventive Maintenance

The preventive maintenance section of the manufacturer's instruction manual of the NDIR monitoring system should contain a trouble shooting guide and diagnostic chart to assist operators in identifying and correcting instrument problems.

10.4 Troubleshooting the Analyzer

10.4.1 The manufacturer's instruction manual generally contains troubleshooting guidelines that cover most troubles which may occur. Table 4 illustrates typical NDIR monitor problems as outlined in a manufacturer's instruction manual.

10.4.2 The troubleshooting guidelines should be used only after the analyzer cannot be calibrated or aligned according to manufacturers' specifications or cannot be operated properly.

10.4.3 If the recording instrument indicates an incorrect value when a sample which contains a low concentration of the component of interest is measured, check the alignment and calibration of the analyzer for optical balance. If the meter does not deflect upscale when span gas is passed through the analyzer and the power indicator is on, check the output circuit. If the power indicator is off, check the power connections. If these or other problems cannot be located or corrected using the specified guidelines, contact the manufacturer for assistance.

11. Performance Criteria and Quality Assurance (QA)

Required quality assurance measures and guidance concerning performance criteria that should be achieved within each laboratory are summarized and provided in the following section.

11.1 Standard Operating Procedures (SOPs)

11.1.1 SOPs should be generated by the users to describe and document the following activities in their laboratory:

- assembly, calibration, leak check, and operation of the specific sampling system and equipment used,
- preparation, storage, shipment, and handling of the sampler system,
- purchase, certification, and transport of standard reference materials, and
- all aspects of data recording and processing, including lists of computer hardware and software used.

11.1.2 Specific stepwise instructions should be provided in the SOPs and should be readily available to and understood by the personnel conducting the monitoring work.

11.2 Quality Assurance Program

The user should develop, implement, and maintain a quality assurance program to ensure that the sampling system is operating properly and collecting accurate data. Established calibration, operation, and maintenance procedures should be conducted on a regularly scheduled basis and should be part of the quality assurance program. Calibration procedures and operation procedures in Section 9.2, and maintenance procedures in Section 10.3 of this method and the manufacturer's instruction manual should be followed and included in the QA program, as outlined in Table 5. Additional QA measures (e.g., trouble shooting) as well as further guidance in maintaining the sampling system should be provided by the manufacturer.

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11.2.1 Precision Check

11.2.1.1 A periodic precision check is used to assess the quality of the data. A one-point check on the analyzer is carried out at least once every 2 weeks at a CO concentration between 8 and 10 ppm.

11.2.1.2 The analyzer must be operated in its normal sampling mode, and the precision test gas must pass through all filters, scrubbers, conditioners, and other components used during normal ambient sampling. The standards from which the precision check test concentrations are obtained must be traceable to a NITS-SRM or a commercially available CRM; the same standards used for calibration may be used for the precision check. They must conform to specifications outlined in Section 8.1 and Section 8.2.

Note: All gas standards used for precision or daily zero and span check should contain about 350 ppm CO_2 to simulate normal ambient concentrations.

11.2.1.3 Connect the analyzer's sample inlet line to a precision gas source that has a concentration between 8 and 10 ppm CO and that is traceable to a NITS-SRM or a CRM as illustrated in Section 9.2.3 and Figure 4. If a precision check is made in conjunction with a zero/span check, it must be made prior to any zero and span adjustments.

11.2.1.4 Allow the analyzer to sample the precision gas for a least 5 min or until a stable recorder trace is obtained.

11.2.1.5 Record this value on the Monthly Maintenance Check Sheet and mark the chart as "unadjusted" precision check.

11.2.1.6 The expected response of the NDIR analyzer should be within 10% of the precision calibration gas standard.

11.2.2 Performance Audit

11.2.2.1 An audit is an independent assessment of the accuracy of data generated by an analyzer.

11.2.2.2 Independence is achieved by having the audit performed by an operator other than the one conducting the routine field measurements and by using audit standards, reference materials, and equipment different from those routinely used in monitoring.

11.2.2.3 The audit should be an assessment of the measurement process under normal operations, that is, without any special preparation or adjustment of the system. Routine quality assurance checks conducted by the operator are necessary for obtaining and reporting good quality data, but they are not to be considered part of the auditing procedure.

11.2.2.4 Proper implementation of an auditing program will ensure the integrity of the data and assess the accuracy of the data.

11.2.2.5 A performance audit consists of challenging the continuous analyzer with known concentrations of CO within the measurement range of the analyzer. Known concentrations of CO can be generated by using individual cylinders for each concentration (see Section 9.2.3.3) or by using one cylinder of a high CO concentration and diluting it to the desired levels with zero-air (see Section 9.2.3.17). In either case, the gases used must by traceable to a NITS-SRM or a commercially available CRM and contain about 350 ppm CO_2 to simulate normal ambient concentrations.

11.2.2.6 A dynamic dilution system must be capable of measuring and controlling flow rates to within ± 2% of the required flow. Flow meters must be calibrated under the conditions of use against a reliable standard such as a soap bubble meter or a wet test meter; all volumetric flow rates should be corrected to STP at 25°C (77°F) and 760 mm Hg (29.92 in Hg); but if both the CO and the zero air flow rates are measured with the same type device at the same temperature and pressure, the STP correction factor in the audit equations can be disregarded.

11.2.2.7 The analyzer should be challenged with at least one audit gas of known concentration from each of the following concentrations within the measurement range of the analyzer being audited:

Audit Point	CO Concentration Range, ppm
1	3 to 7
2	8 to 12
3	18 to 22
4	28 to 32
5	33 to 42

The difference in CO concentration (ppm) between the audit value and the measured value is used to calculate the accuracy of the analyzer.

11.2.2.8 All measurements of audit concentrations should fall within ± 10% of the audit value.

12. Method Safety

This procedure may involve hazardous materials, operations, and equipment. This method does not purport to address all of the safety problems associated with its use. It is the user's responsibility to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to the implementation of this procedure. This should be part of the user's SOP manual.

13. References

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13. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II - Ambient Air Specific Methods* - Section 2.0.7, U.S. Environmental Protection Agency, Quality Assurance Division, Research Triangle Park, NC, 27711, EPA-600/4-77-0272, May, 1987.

Table I. Commercially Available NDIR CO Analyzers Designated by U.S. EPA as References Methods and Other Commercially Available CO and CO_2 Analyzers

Identification	Manufacturer	Fed. Register Notice Vol.	Page	Date
Bendix or Combustion Engineering Model 8501-5CA Infrared CO Analyzer, operated on the 0-50 ppm range and with a time constant setting between 5 and 16 seconds.	Combustion Engineering, Inc. Process Analytics P.O. Box 831 Lewisburg, WV 24901	41	7450	2/18/7
Beckman Model 866 Ambient CO Monitoring System, consisting of the following components: Pump/Sample-Handling Module, Gas Control Panel, Model 865-17 Analyzer Unit, Automatic Zero/Span Standardizer; operated with a 0-50 ppm range, a 13 second electronic response time.	Beckman Instruments, Inc. Process Instruments Div. 2500 Harbor Boulevard Fullerton, CA 92634	41	36245	8/27/7
LIRA Model 202A Air Quality Carbon Monoxide Analyzer System, consisting of a LIRA Model 202S optical bench (P/N 459839), a regenerative dryer (P/N 464084), and rack-mounted sampling system; operated on a 0-50 ppm range, with the slow response amplifier.	Mine Safety Appliances Co. 600 Penn Center Blvd. Pittsburgh, PA 15208	42	5748	1/31/7
Horiba Models AQM-10, AQM-11, and AQM-12 Ambient CO Monitoring Systems, operated on the 0-50 ppm range, with a response time setting of 15.5 seconds.	Horiba Instruments, Inc. 1021 Duryea Ave. Irvine Industrial Complex Irvine, CA 92714	43	58429	12/14/
Monitor Labs Model 8310 CO Analyzer, operated on the 0-50 ppm range, with a sample inlet filter.	Monitor Labs, Inc. 10180 Scripps Ranch Blvd. San Diego, CA 92131	44 45	54545 2700	9/20/7 1/14/8

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Table 1. Commercially Available NDIR CO Analyzers Designated by U.S. EPA as References Methods and Other Commerically Available CO and CO_2 Analyzers (Cont'd)

Identification	Manufacturer	Fed. Register Notice Vol.	Page	Date
Horiba Model APMA-300 Ambient Carbon Monoxide Monitoring System, operated on the 0-20/ 50/100 ppm range with a time constant switch setting of #5. The monitoring system may be operated at temperatures between 10-40°C.	Horiba Instruments, Inc. 1021 Duryea Ave. Irvine Industrial Complex Irvine, CA 92714	45	72774	11/03/80

Other Commercially Available NDIR CO Analyzers

Model #	Manufacturer	Portability
Gas Analyzer Model RI-550A	CEA Instruments Box 303 Emerson, NJ 07630 (201)967-5660	Portable

Commercially Available NDIR CO_2 Analyzers

Model #	Manufacturer	Portability
Gas Analyzer Model 8000	Automated Custom Sys., Inc. 1238 West Grove Ave. Orange, CA 92665 (714)974-5560	Stationary
Gas Analyzer Model RI-411A	CEA Instruments Box 303 Emerson, NJ 07630 (201)967-5660	Portable
Closed Room Monitor Model 4776	Gastech, Inc. 8445 Central Ave. Newark, CA 94560 (415)794-6200	Portable
Gas Analyzer Model APBA-210	Horiba Instruments 1021 Duryea Ave. Irvine Industrial Complex Irvine, CA 92714 (800)556-7422	Portable

Table 1. Commercially Available NDIR CO Analyzers Designated by U.S. EPA as References Methods and Other Commerically Available CO and CO_2 Analyzers (Cont'd)

Commercially Available NDIR CO_2 Analyzers (Cont'd)

Model #	Manufacturer	Portability
LIRA 3200	MSA Instrument Div. Box 427 Pittsburgh, PA 15230 (800)672-4678	Stationary

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Table 2. Suggested Performance Specifications for NDIR CO Analyzers

Analyzer Parameter	Specification
Range (minimum)	0-50 ppm (0-58 mg/m^3)
Lower detection limit (LDL)	1.0 ppm (0.6 mg/m^3)
Lag time (maximum)	20 seconds
Rise time, (95% maximum)	15 minutes
Fall time, (95% maximum)	15 minutes
Zero drift (maximum)	± 1% per day and ± 2% per 3 days
Span drift (maximum)	± 1% per day and ± 2% per 3 days
Precision (maximum)	± 0.5%
Operational period (maximum)	3 days
Noise (maximum)	± 0.5%
Interference equivalent (maximum)	1% of full scale
Operating temperature range	5-40°C
Operating temperature fluctuation	± 5%
Linearity (maximum)	1%
Operating humidity range (maximum)	10-100%

Table 3. Typical NDIR Carbon Monoxide/Carbon Dioxide Analyzer Routine Servicing Schedule

Service	Frequency
Zero/span/precision checks	Daily
Zero/span/potentiometer settings	Daily
Range position checks	Each Visit
Sample & reference flow check	Each Visit
Replace sample inlet particulate filter	Weekly
Leak check system	Weekly
Manual precision check	Weekly
Inspect water removal system	Monthly
Inspect span gas solenoid valve	Monthly
Multipoint calibration	Monthly
Clean sample/reference filters	Quarterly
Electronic bias adjustment	Semi-Annually
Source balance adjustment	Semi-Annually
Cell wall & window inspection	Annually
CO_2 interference test	Annually
H_2O interference	Annually

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Table 4. Typical NDIR Monitor Problems

Observation	Possible Cause	Diagnostic Check
CO level too low	Reference infrared source source failing	Run span gas check
	Sample lines clogged	Check with flow meter
	Decreased pressure in sample compartment of detector	Check after inspection of infrared source
	Vacuum pump failure	Inspect pump
	Amplifier failing	Completely check-out electronics system
CO level too high	Sample infrared source failing	Run span gas check
	Sample cell optics dirty	Inspect and clean if necessary
	Decreased pressure in reference compartment of detector	Run span gas check after inspection of infrared source
	Amplifier failing	Completely check-out electronics system
Abnormal positive zero drift	Moisture elimination devices inoperative	Recharge silica gel; check refrigeration unit
	Dirty optical surfaces	Clean cells as necessary; check particulate filter
	Amplifier failing	Check-out electronics system completely
		Run span check

Table 5. QA/QC Operational Parameters

QA/QC Parameters	Actions
Calibration gas en concentration	Measurement of control samples as part of the auditing program.
Data processing errors	Data processing checks performed as a part of the auditing program.
Zero drift	Zero check and adjustment before each sampling period as part of routine operating procedure.
Span drift	Span check and adjustment before each sampling period as part of routine operating procedure.
System noise	Check of strip chart record trace for signs of noise after each sampling period as part of routine operating procedure.
Sample cell pressure variation	Reading and recording sample cell pressure at the beginning and end of a sampling period as part of routine operating procedure.
Temperature variation	Minimum-maximum thermometer placed near the analyzer, or any other temperature-indicating device, read periodically throughout the sampling period. This would usually be done as a special check.
Voltage variation	A.C. voltmeter measuring the voltage to the analyzer and read periodically throughout the sampling period. This would usually be done as a special check.

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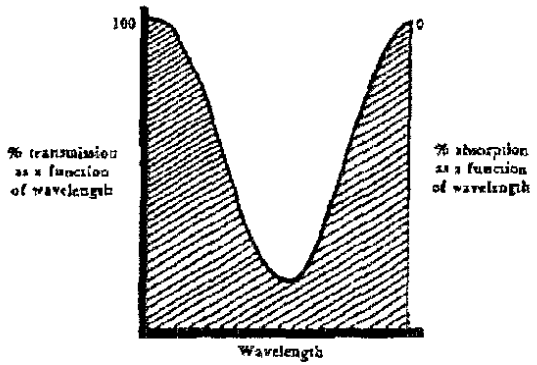

Figure 1A. Typical Absorption Curve in the IR

Gas	Location of band centers (μm)	Wave number (cm^{-1})
NO	5.0-5.5	1800-2000
NO_2	6.5-20	500-1500
SO_2	8-14	700-1250
H_2O	2.7	1500-1400v
	5.0-5.5	1600-2000
	7.1-10	1200
CO	2.3	2200
	4.6	4300
CO_2	2.7	650-1250
	5.2	1900
	8-12	1700
NH_3	10.5	950
CH_4	3.3	1300
	7.7	3000
Aldehyde	8.4-8.9	1350-1950

Figure 1B. Infrared Band Centers of Some Common Gases

Figure 1. Typical Absorption Curve (Figure 1A) in the IR and Infrared Band Centers (Figure 1B) of Some Common Gases

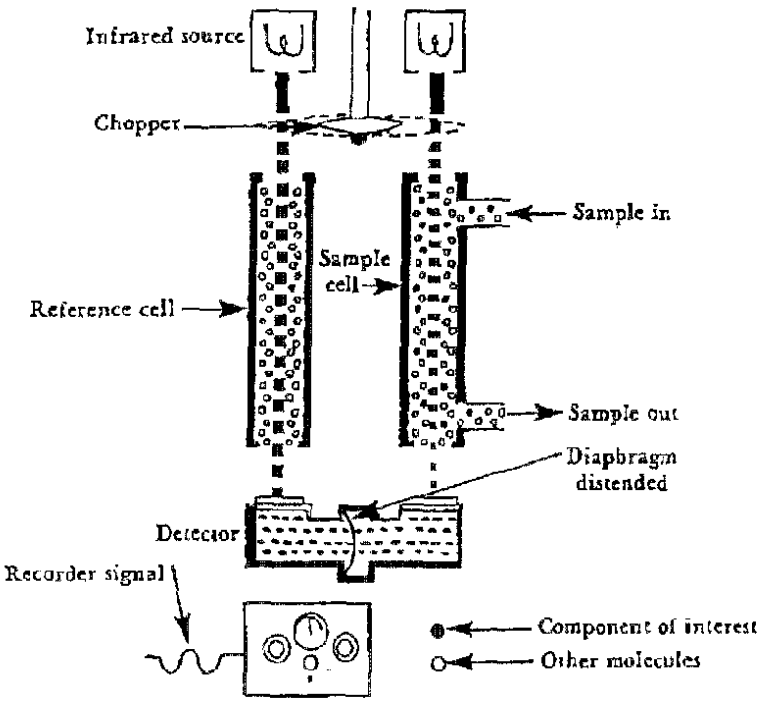

Figure 2. Major Components of a Commercially Available NDIR Instrument

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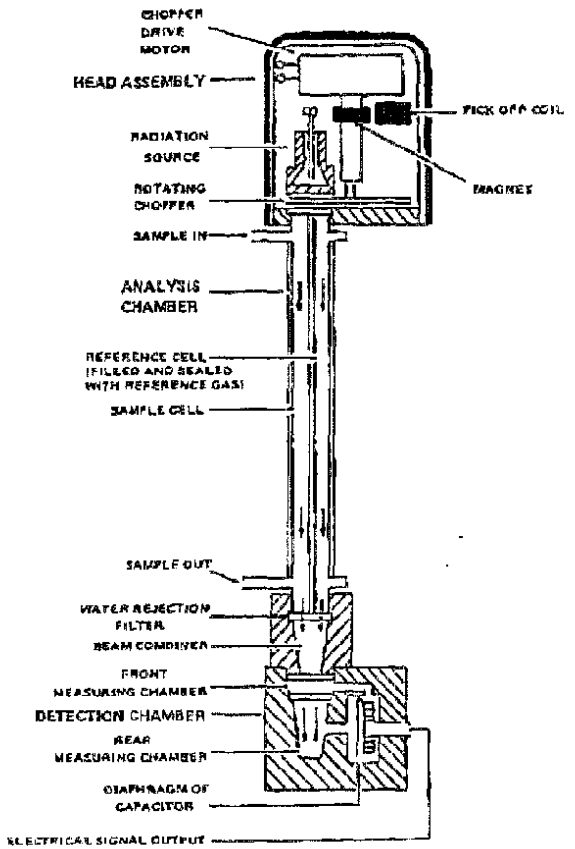

Figure 3. Front/Rear Chamber Detector Design

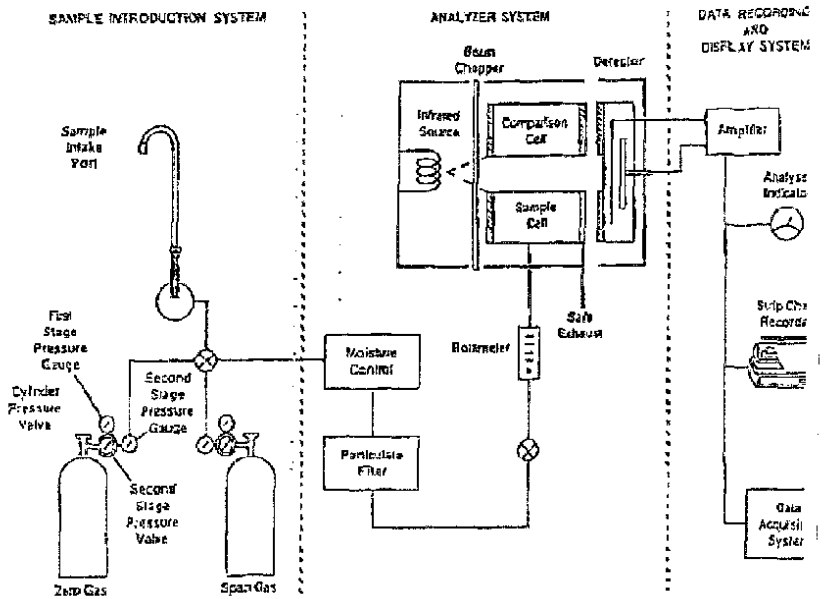

Figure 4. NDIR Calibration and Detector System

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ADJUSTED ZERO AND SPAN VALUES			ANALYZER CALIBRATED
	% CHART	PPM	
ADJ. ZERO			LOCATION
ADJ. SPAN			S/N SITE NO.
TEMP °C	PRESS Torr		DATE
RANGE	TIME CONSTANT		DATE LAST CALIBRATED

INPUT		ANALYZER RESPONSE	
PPM	% CHART	% CHART	PPM

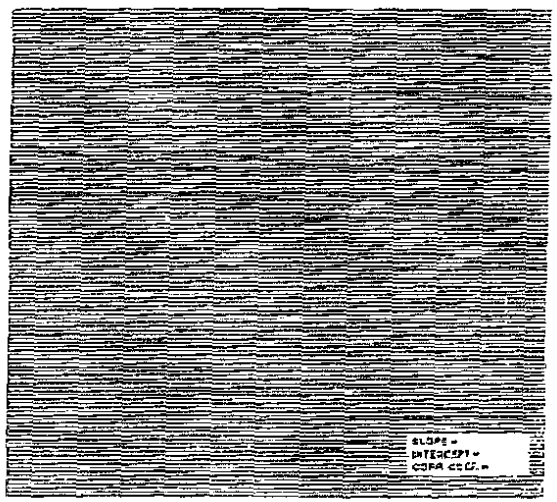

Figure 5. Multipoint Calibration Data Sheet

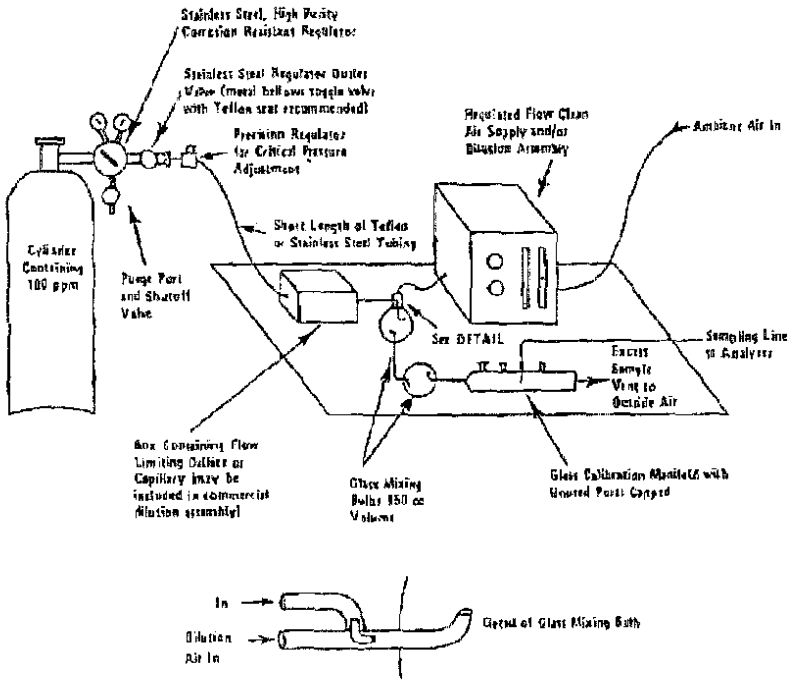

Figure 6. Assembly for Dilution of CO from Cylinder for Use in Calibration or Span Check

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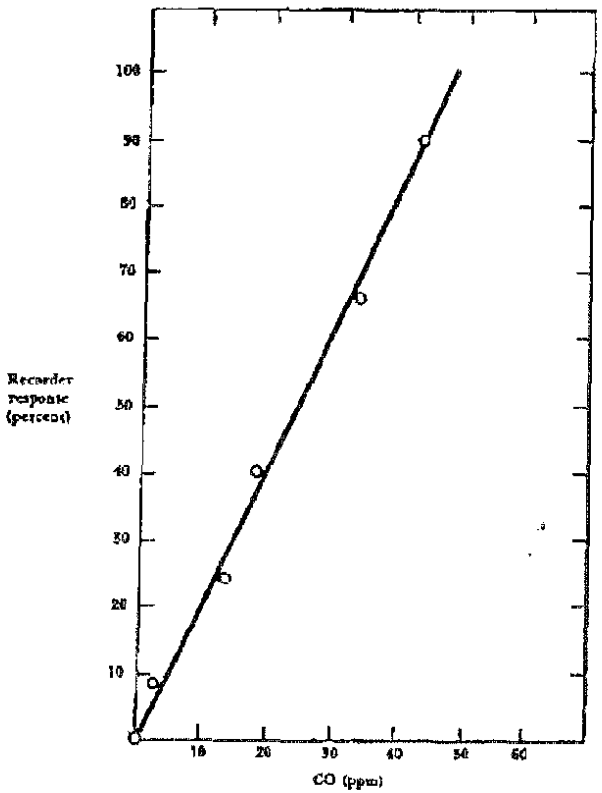

Figure 7. NDIR Calibration Curve

Monthly Maintenance Check List

SITE NUMBER _____ TECHNICIAN _____

ANALYZER S/N _____

DATE	READING: DIAL/CHART (ppm)				FLOW SETTING					PARTICULATE FILTER	CYL. PRESSURE	
	ZERO		SPAN		SAMPLE		REFERENCE				ZERO	SPAN
	UNADJ.	ADJ.	UNADJ.	ADJ.	UNADJ.	ADJ.	UNADJ.	ADJ.			#	#

OPERATOR INSTRUCTIONS:

1. DAILY: ZERO/SPAN/PRECISION CHECK
2. EACH VISIT: CHECK FLOW SETTING; CHART TRACE
3. WEEKLY: REPLACE PARTICULATE FILTER;
4. MONTHLY: INSPECT WATER TRAP FILTER; INSPECT SPAN GAS SOLENOID VALVE - DATE LAST CHECKED _____ ZERO AIR _____ ZERO AIR WITH SPAN GAS _____
5. QUARTERLY: CLEAN SAMPLE/REFERENCE FILTERS; MULTI-POINT CALIBRATION; SPAN GAS TO SPAN GAS INLET _____ SPAN GAS TO SAMPLE INLET _____
6. SEMI-ANNUALLY: ELECTRONIC BIAS ADJUSTMENT - DATE LAST CHECKED _____ SOURCE BALANCE ADJUSTMENT - DATE LAST CHECKED _____
7. ANNUAL: INSPECT CELL WALLS AND WINDOWS - DATE LAST CHECKED _____ CO_2 INTERFERENCE TEST - DATE LAST CONDUCTED _____ H_2O INTERFERENCE TEST - DATE LAST CONDUCTED _____

DATE	COMMENTS OR MAINTENANCE PERFORMED

Figure 8. Monthly Maintenance Check Sheet

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